A Membrane Array Using T/R Membranes

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Outline

- Motivation for Membrane Antennas
- Applications of Large Aperture Membrane Arrays
- Flex-Compatible Transmit/Receive (T/R) Modules
- A 2x4 Element Active Membrane Array
- Future Work

Application: Geosynchronous or MEO SAR

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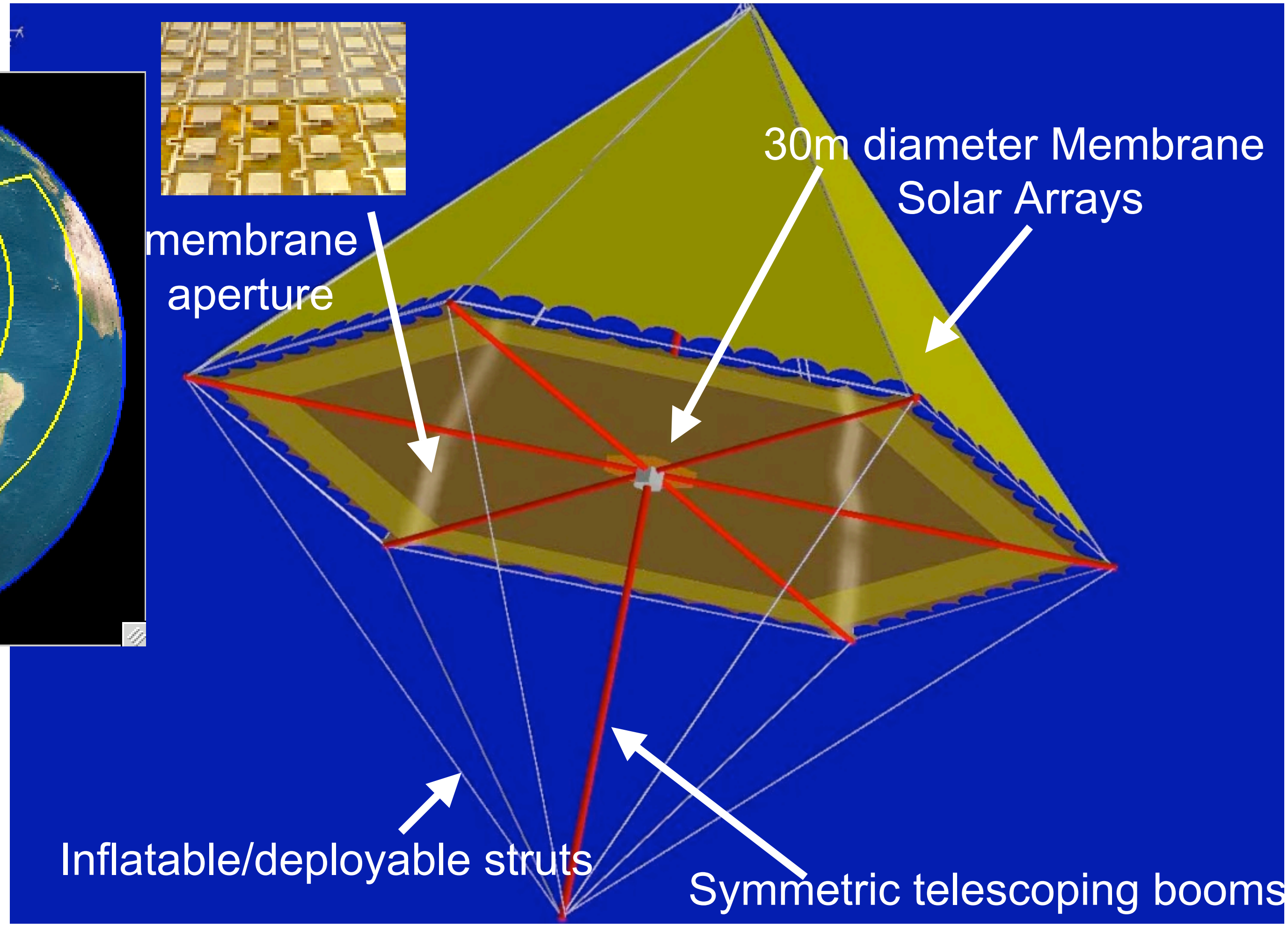
Coverage

— satellite track on the ground



A conceptual drawing of a 30m diameter phased array at Geosynchronous orbit.
A membrane antenna is assumed for the phased array.

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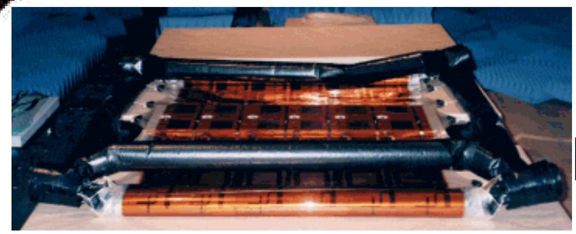
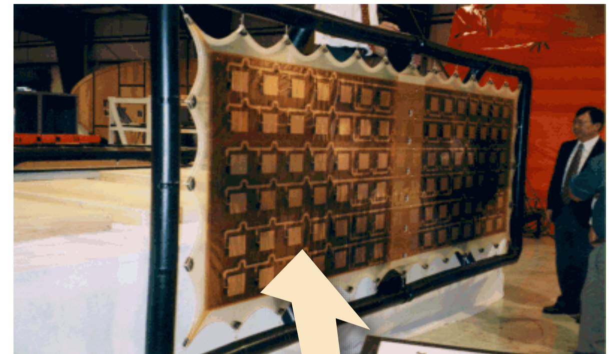
Motivation

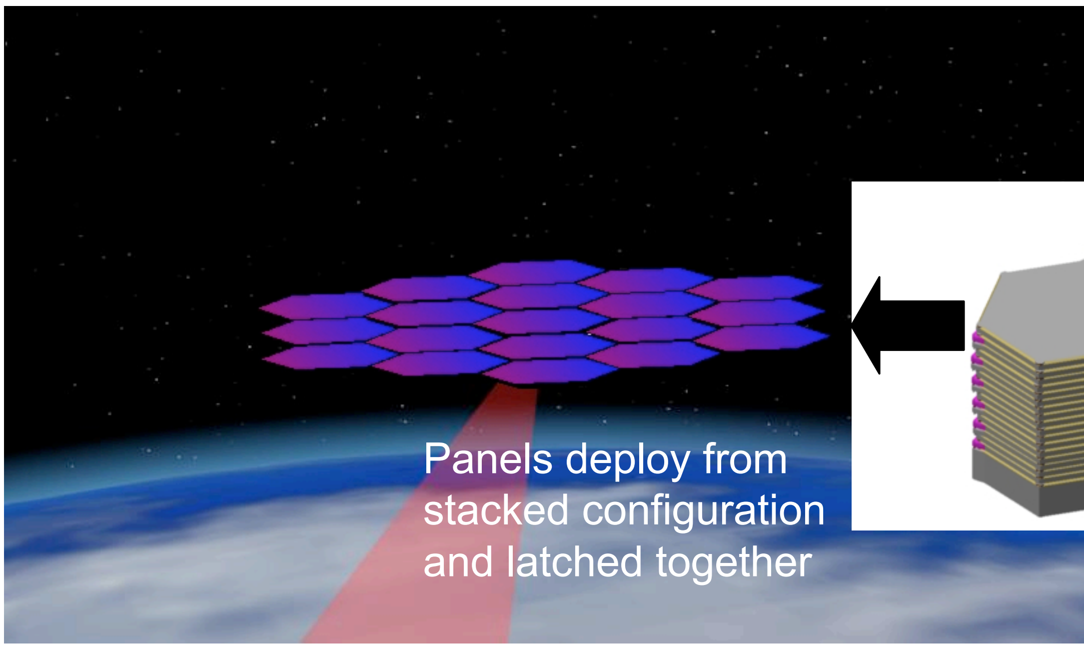
Roll-up SAR Antenna (stowed)

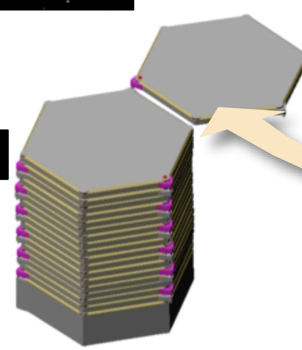


Roll-up SAR Antenna (partially deployed)



Roll-up SAR Antenna (deployed)





Phased Array Electronics

Rigid arrays

$10\text{-}20 kg/m^2$

Membrane antennas

$<2 kg/m^2$

x10 Reduction in Volume

Applications

Applications for L-band Synthetic Aperture Radar (SAR)

- Surface deformation and strain measurement. This can be used for monitoring seismic and volcanic activity

- Natural and manmade hazard monitoring, assessment and disaster response, mud slides, floods etc

- Soil moisture measurement, biomass, land cover change, ocean circulation and ice motion

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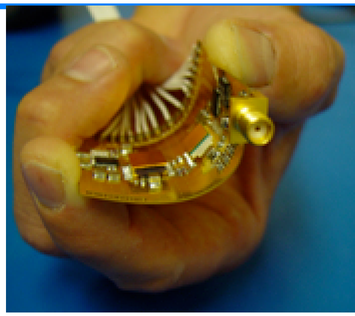
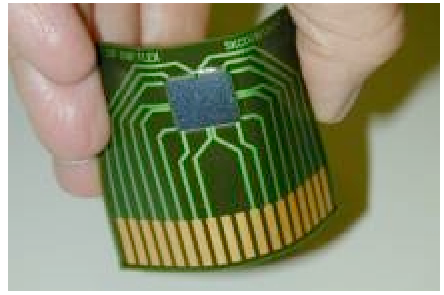
Active Membrane Antenna

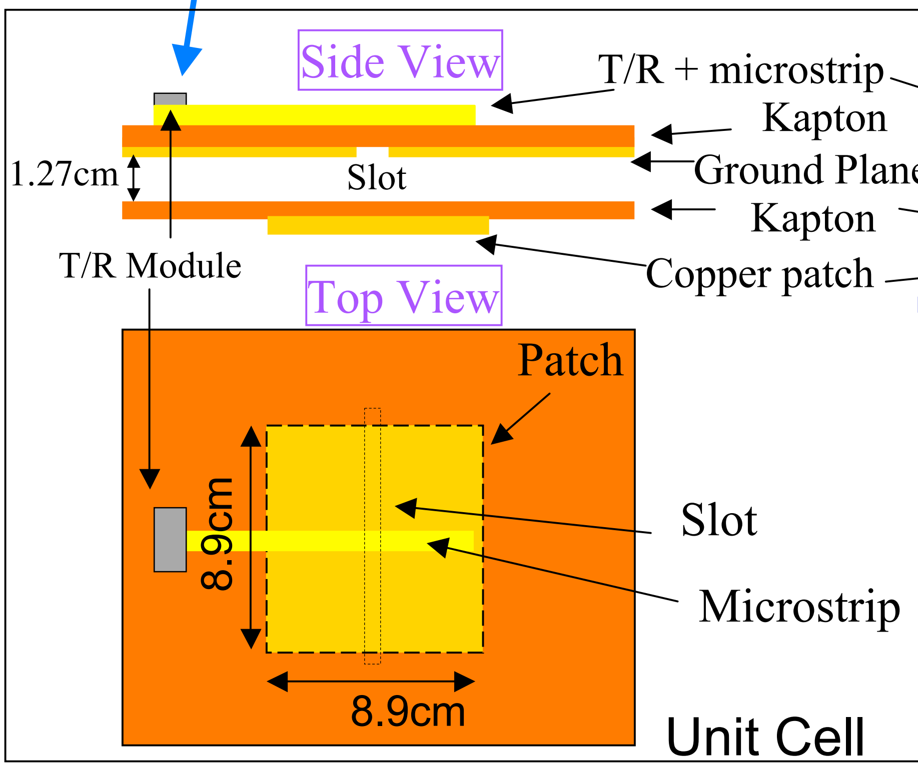
Membrane-compatible T/R Development

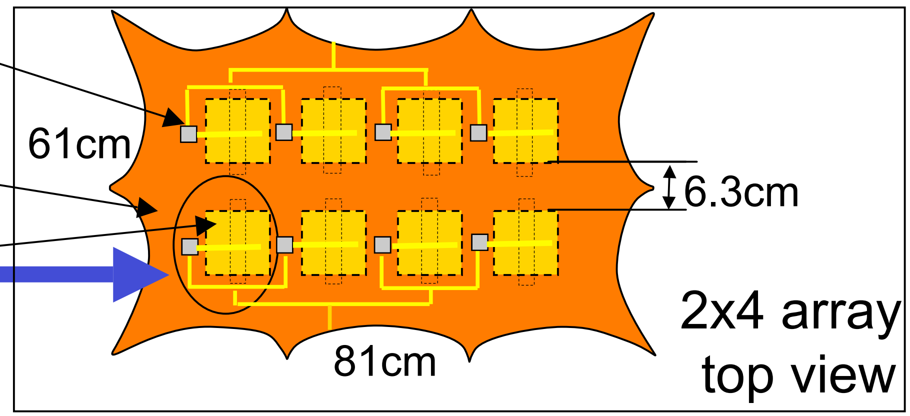


Hybrid T/R, packaged parts
(Current Work)



Single chip integrated T/R
(Future Work)





Kapton thickness: 50μm

Copper thickness: 9μm

T/R Module:

L-Band T/R Module

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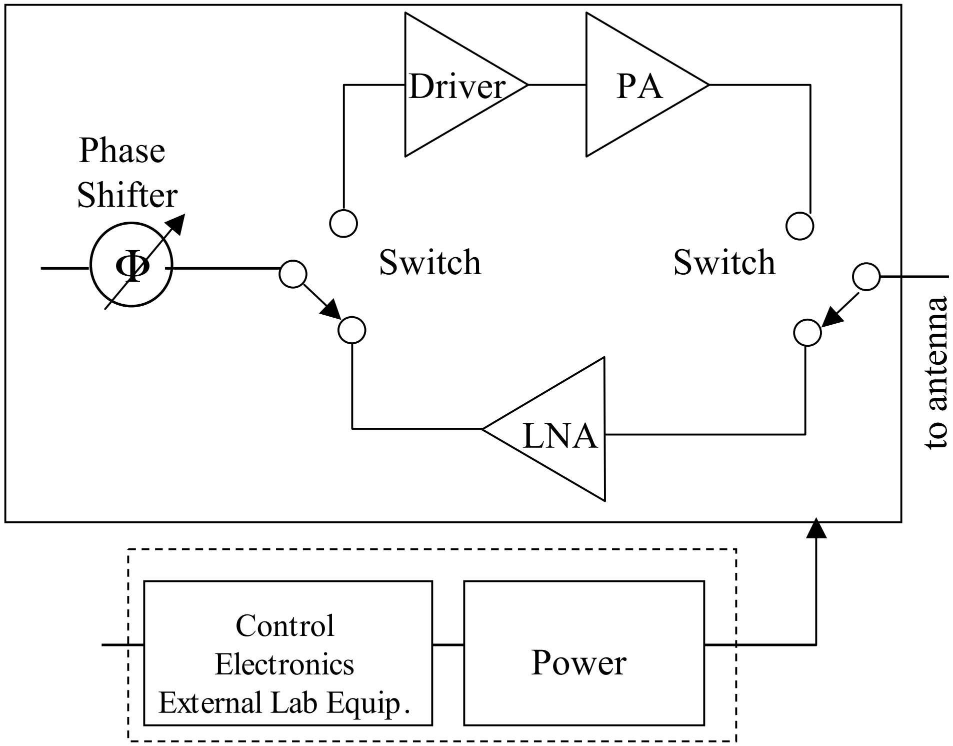
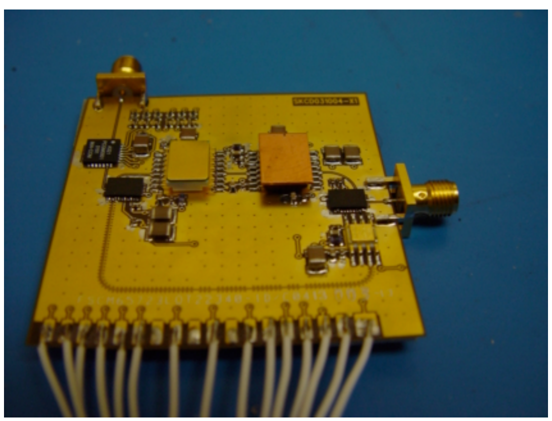
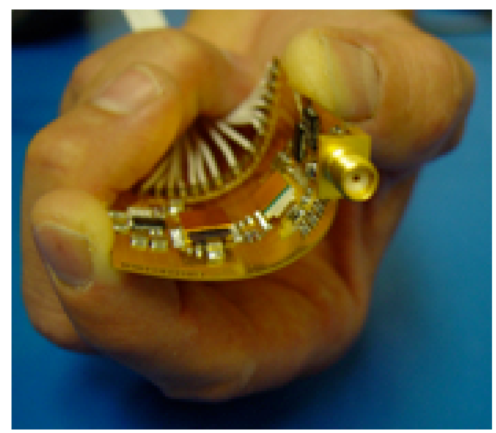


T/R Module Block Diagram

T/R Module Preliminary Specs	
Frequency:	1220 –1300 MHz
Bandwidth:	80MHz
Tx Peak Power:	4W (1W this design)
Tx Average Power:	0.8W
Duty Cycle:	1 to 20%
Max PRF:	200Hz (GEO) 2KHz (LEO)
Max Pulse Width:	1000usec (GEO), 50-100usec (LEO)
Tx/Rx Gain:	30/20dB
Phase Shifter Bits:	6bits
NF:	<3 dB



Multi-layer Flex T/R Module
(3-metal Layers)



Additional Requirements and Challenges

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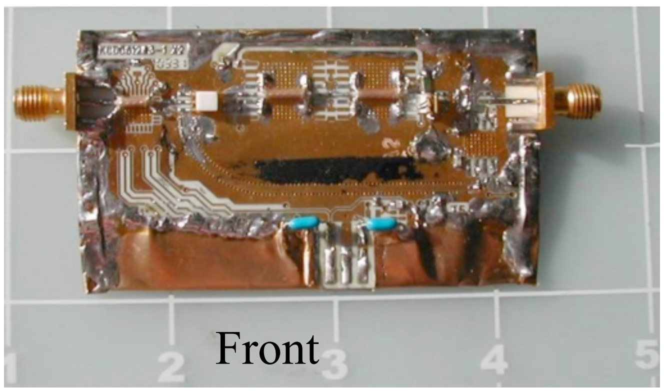
Requirements:

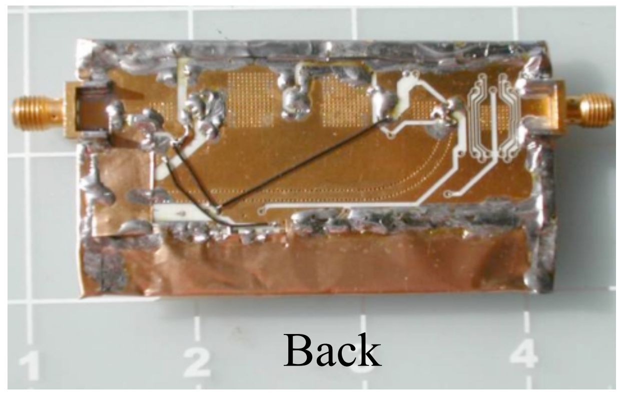
- Low profile
- Mechanically flexible

Challenges:

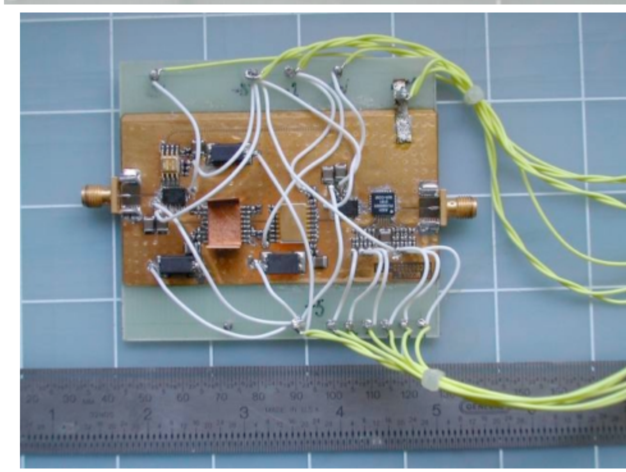
- No enclosure/package
- Thin substrate (experimented with 2 & 3 metal layers)
- Problems with instability
- Transmit and receive isolation
- Accurate etching of 50Ω lines (100μm) on flex substrate (50μm)

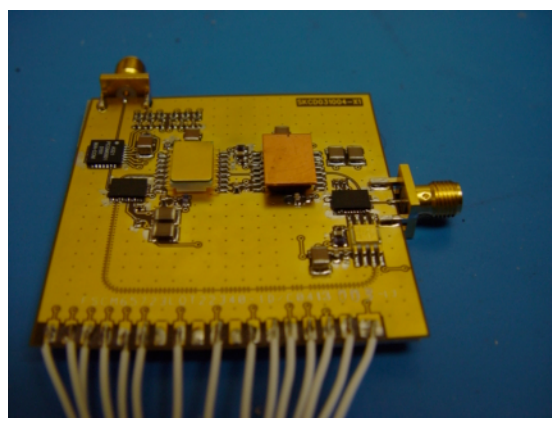


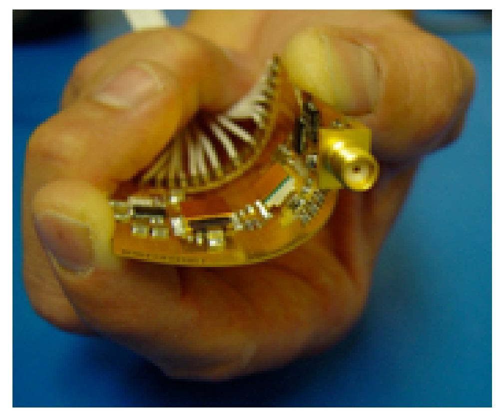
Front



Back







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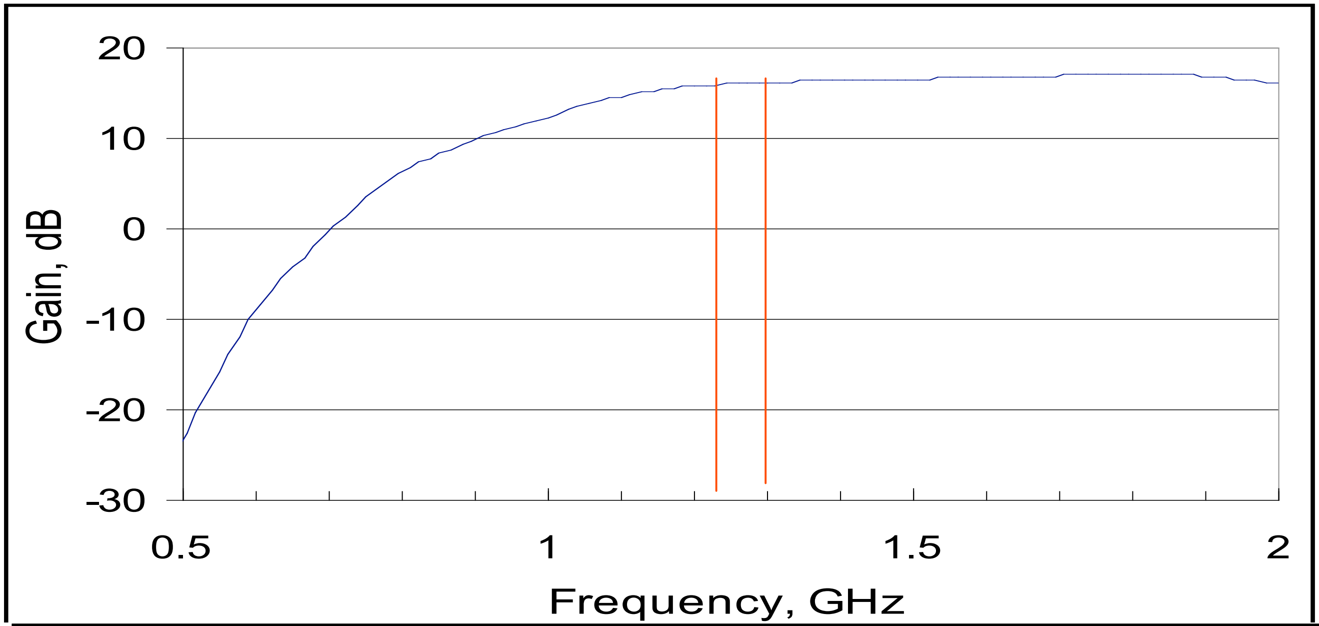
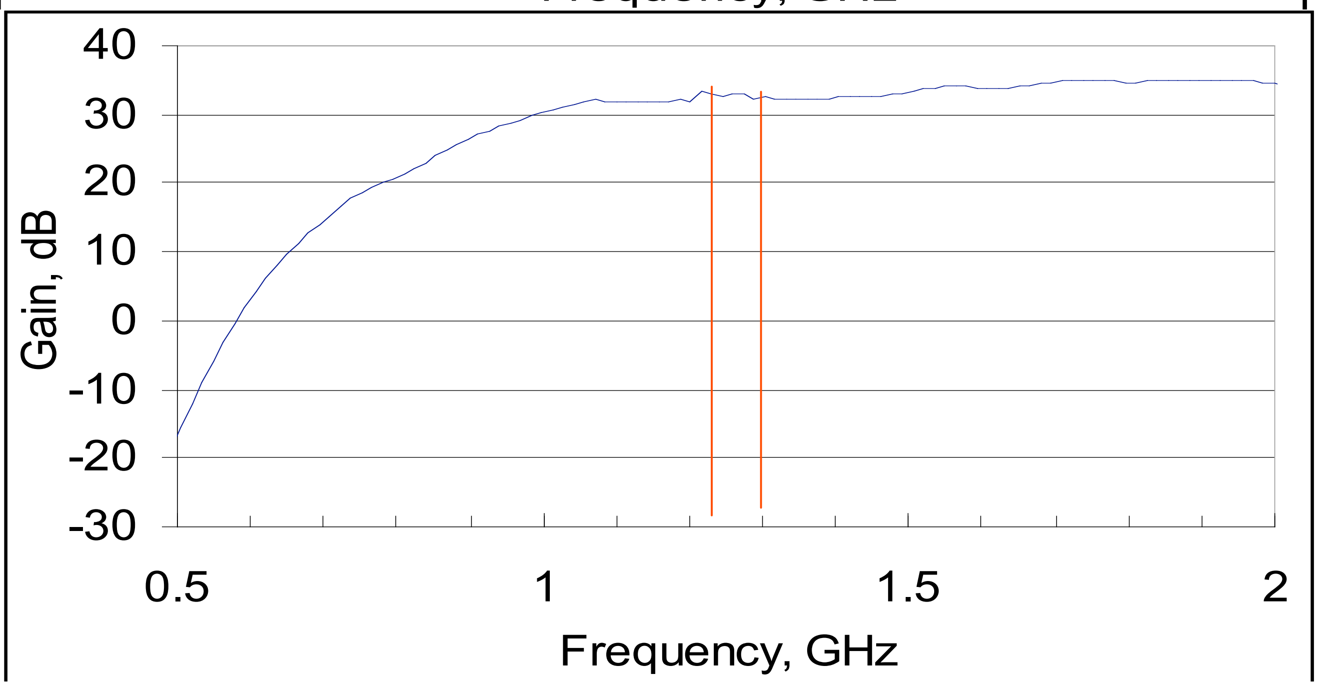
T/R Module Gain



Freq. : 1.22-1.3GHz

Receive gain = 17 dB

Gain Flatness: <0.5dB

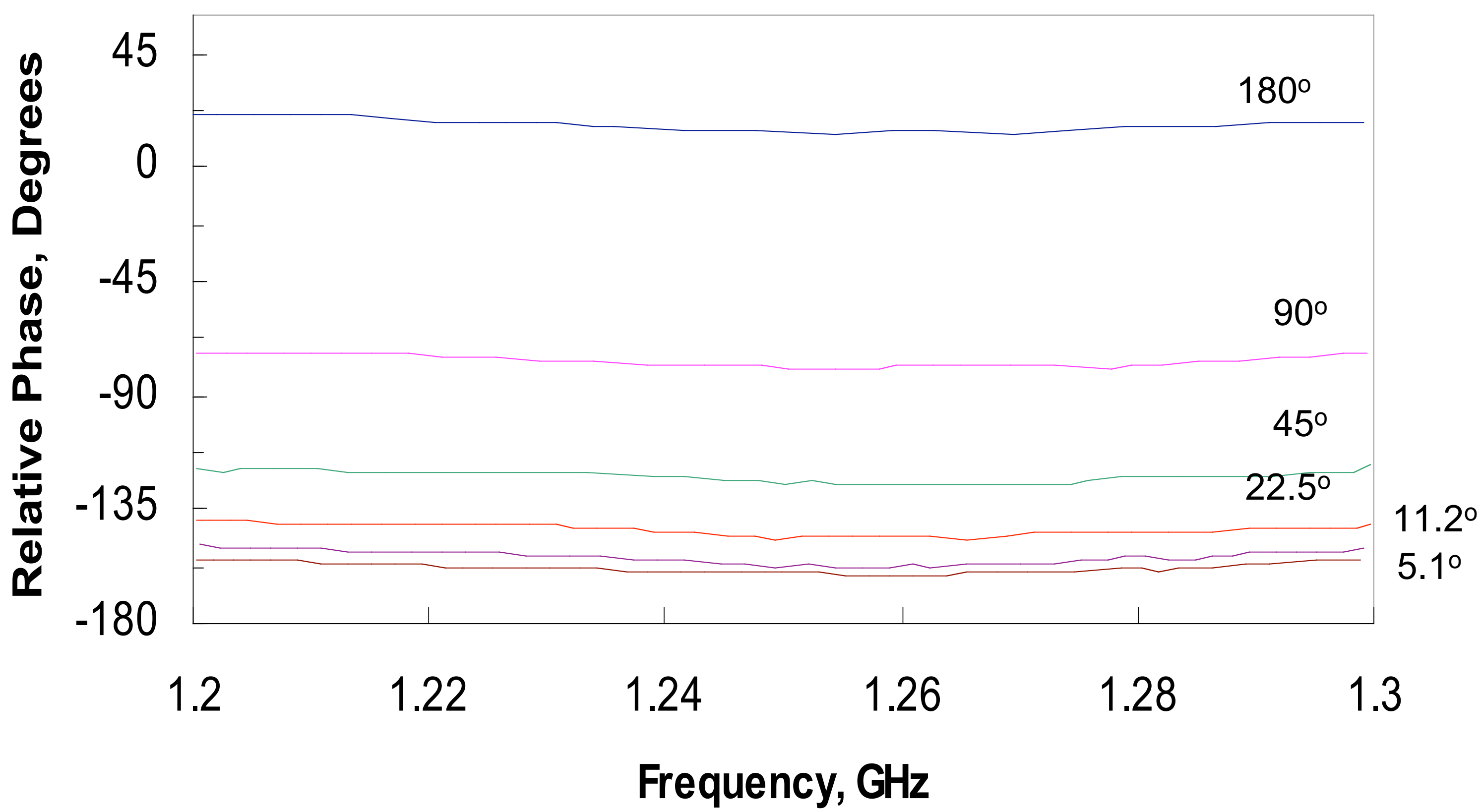


Transmit gain = 32 dB

Gain Flatness: <0.5dB

T/R Module Phase

- Measured phase shifts very close to nominal



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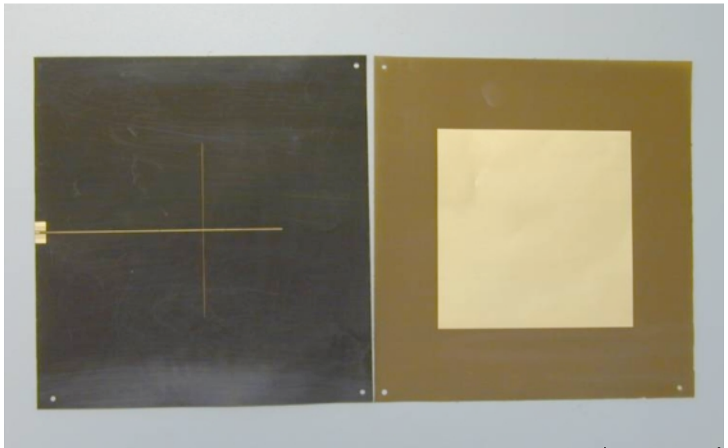
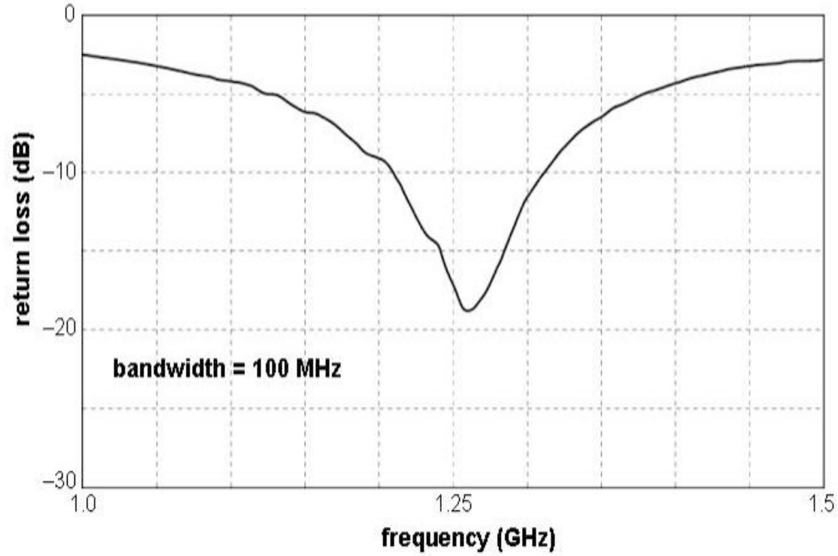
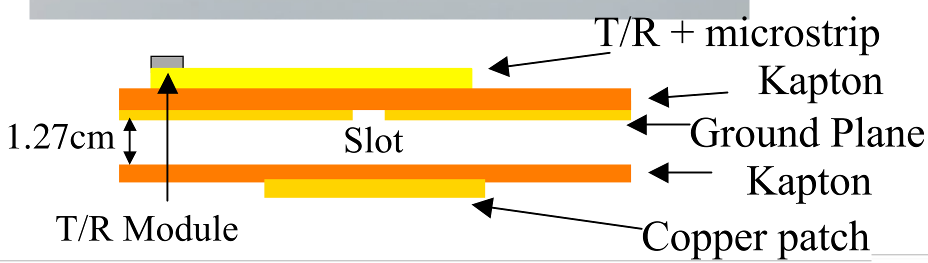
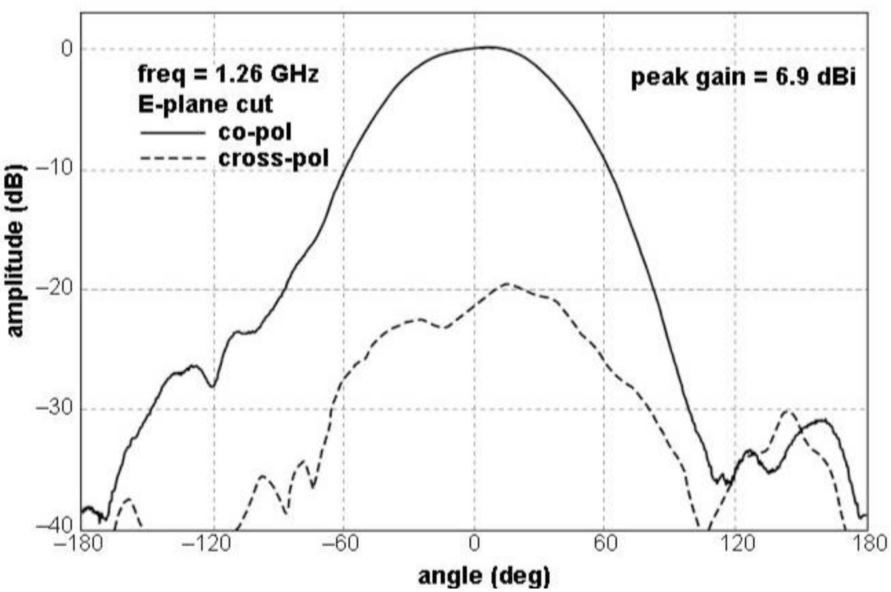
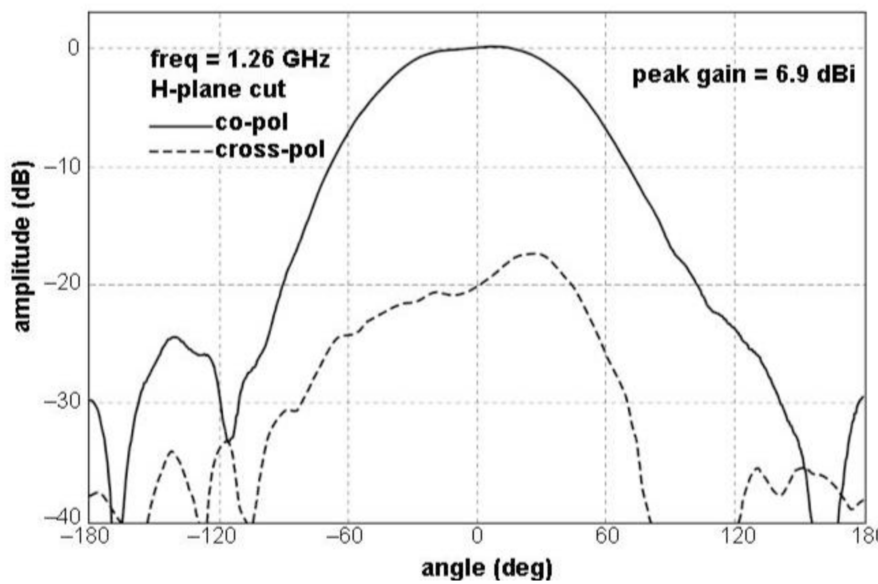
Antenna Feed Measured Results











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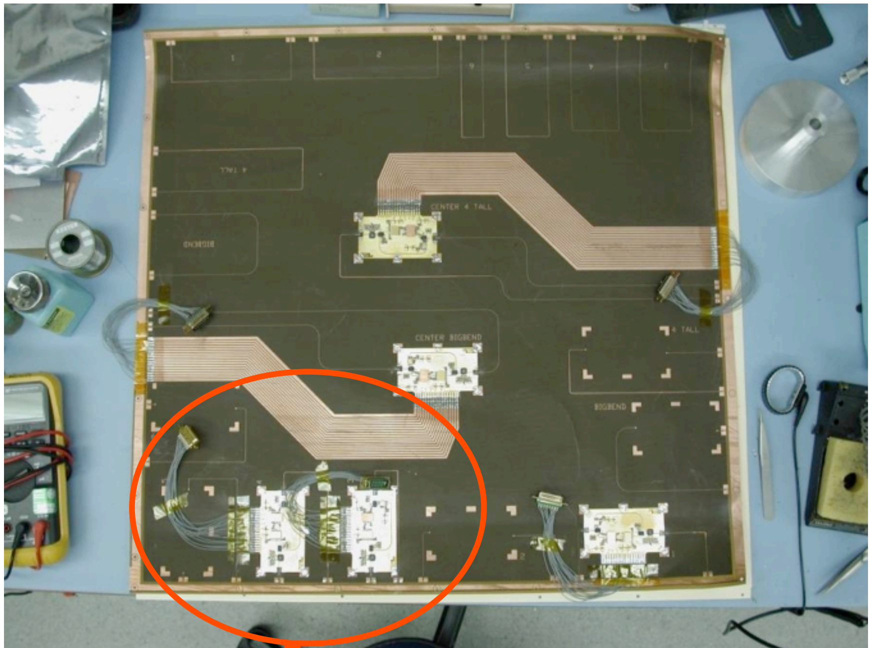
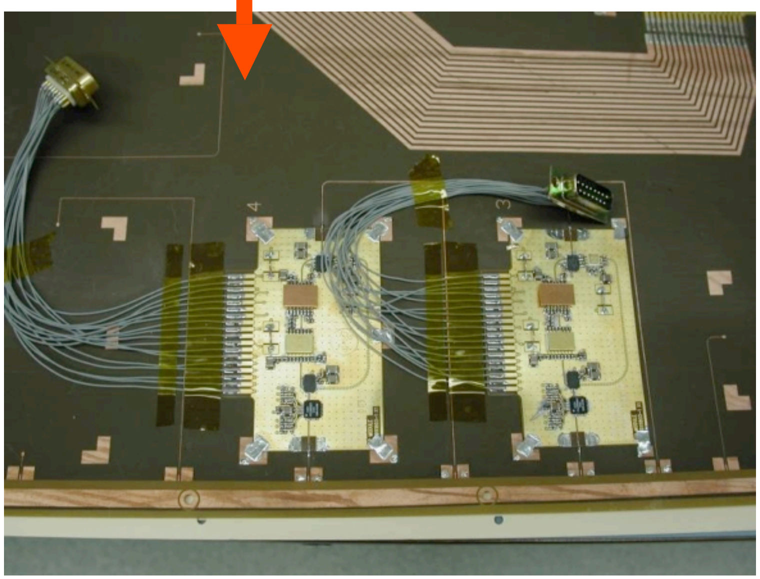
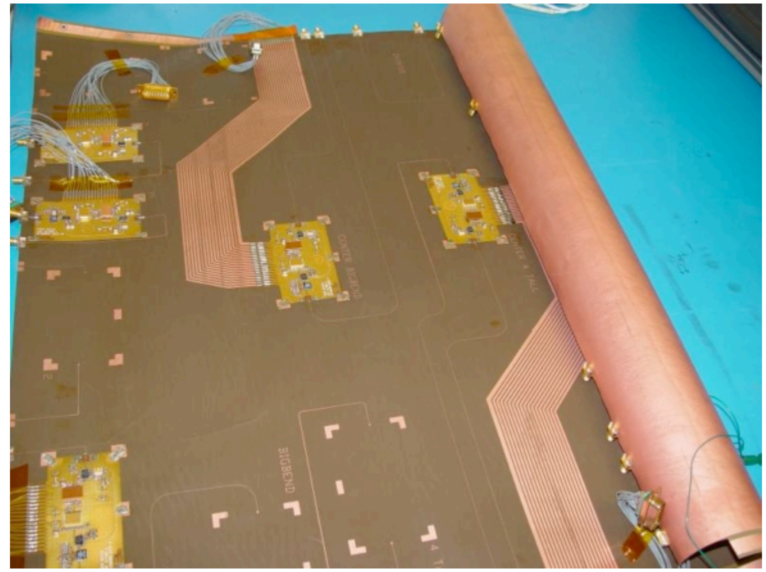
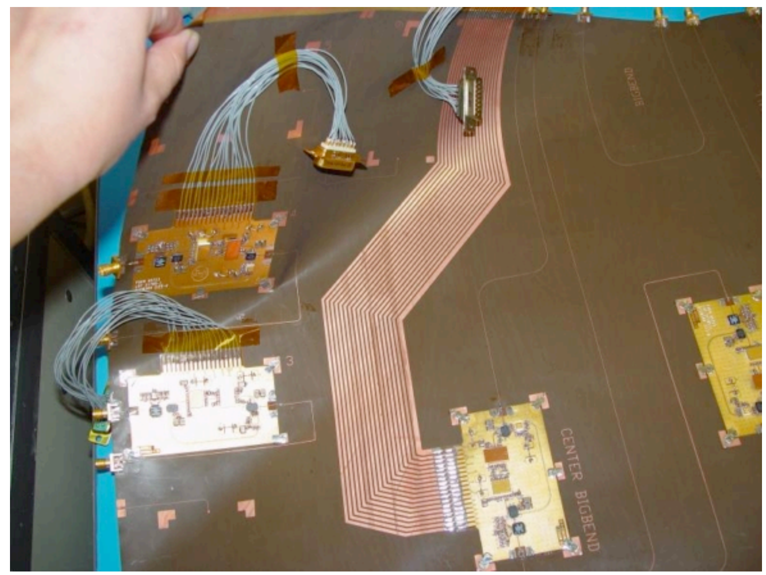
T/R Integration with Membrane









Membrane Antenna and Frame Assembly

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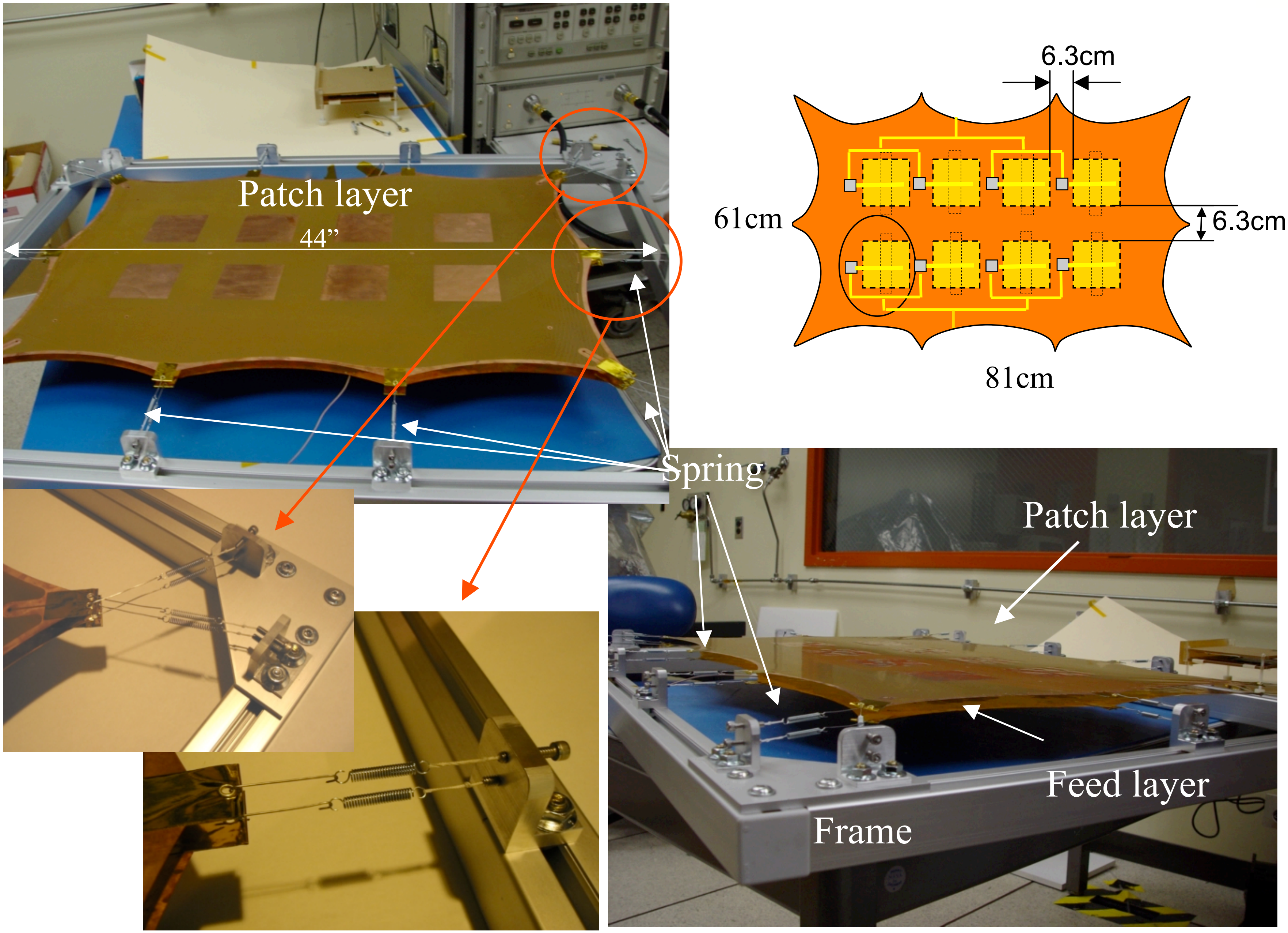
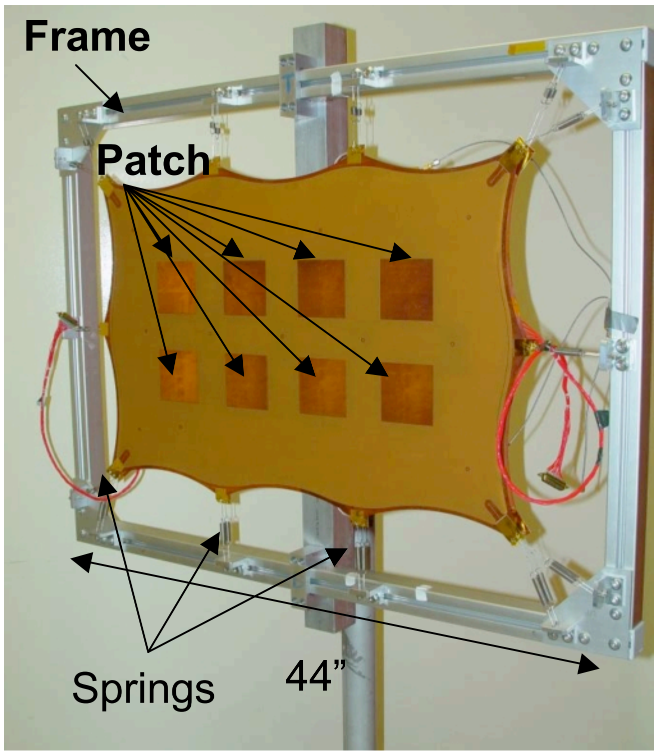
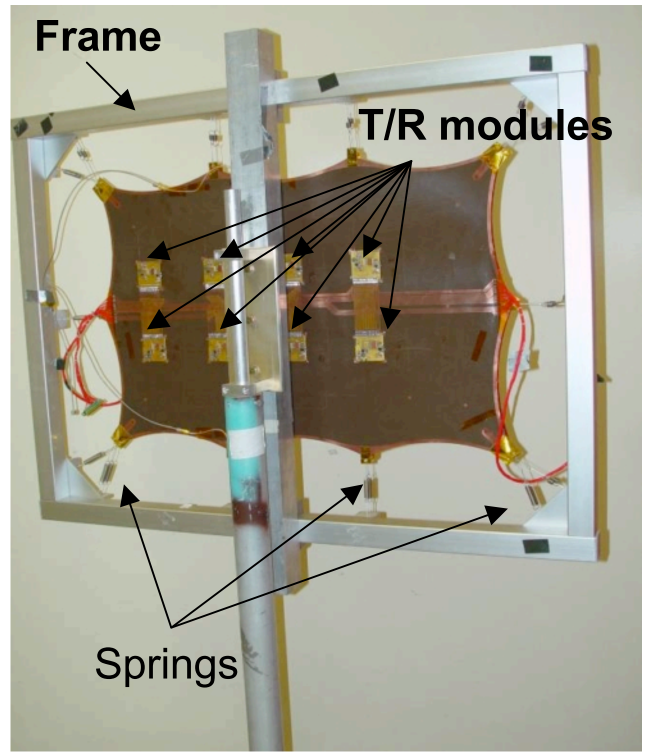


2x4 Element Active Membrane Phased Array

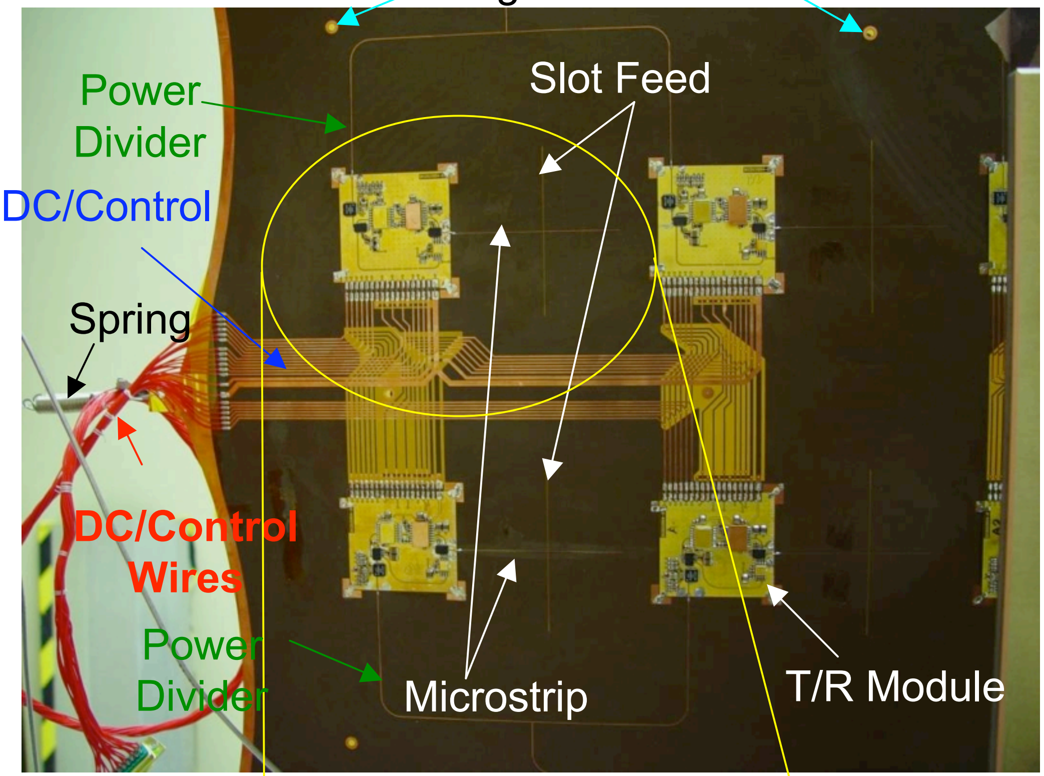
Active array layer 1: consisting of radiating patches

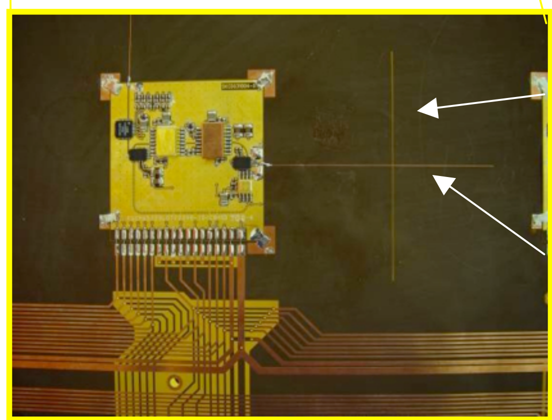


Active array layer 2 (0.5" from layer 1): consisting of T/R modules and antenna feeds.

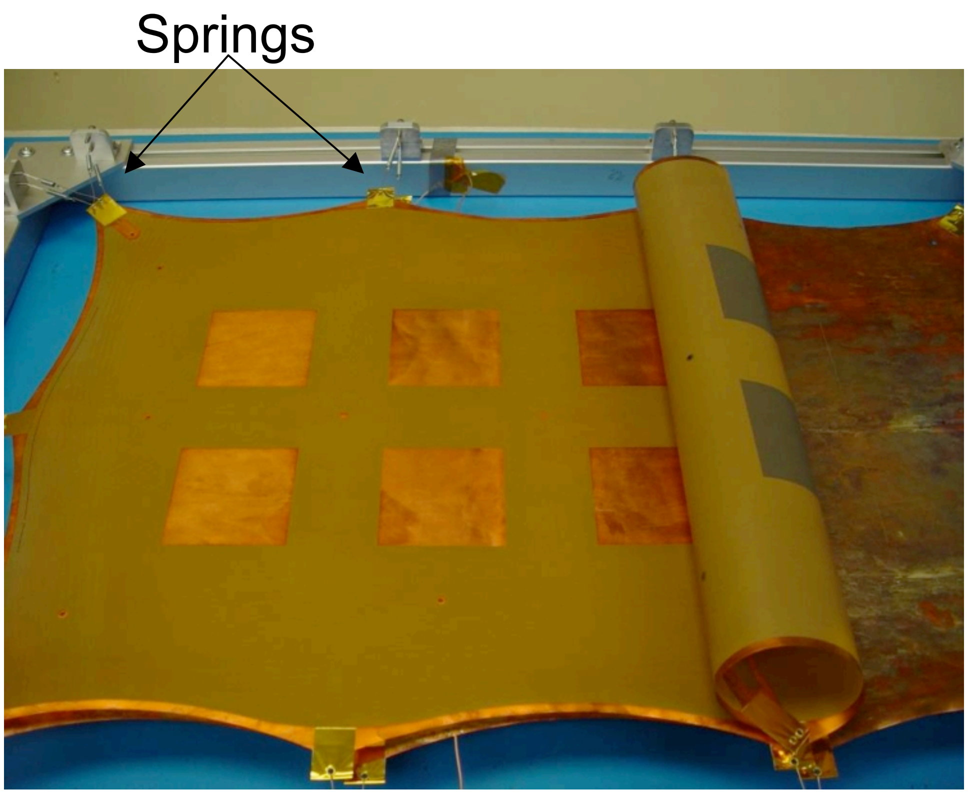


Phased Array Close-up





Phased Array in Rolled Configuration



The antenna is stowed in rolled configuration

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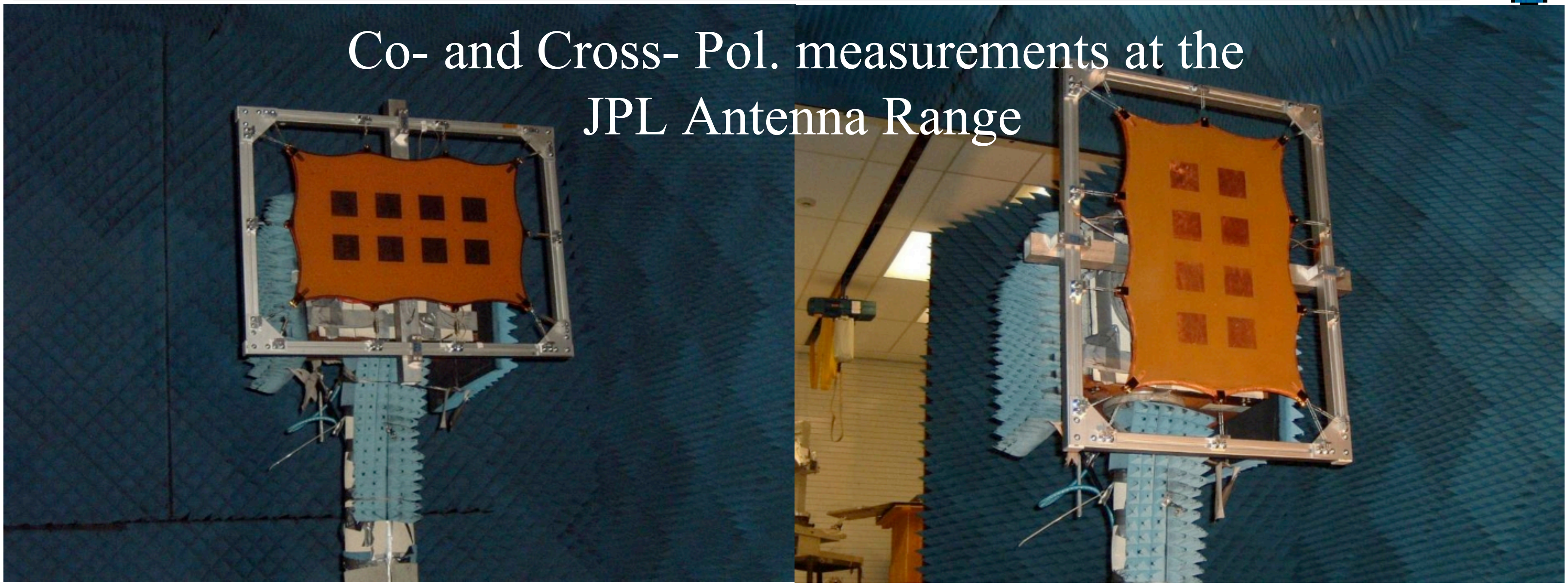
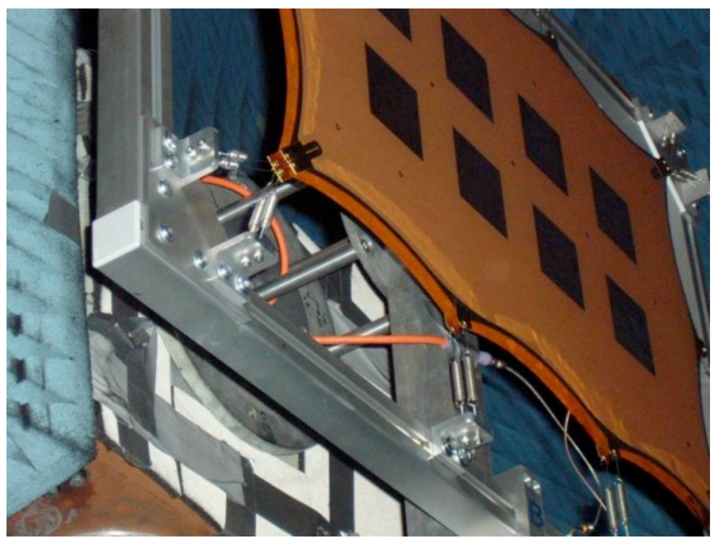
Antenna Measurement Setup

Co- and Cross- Pol. measurements at the JPL Antenna Range

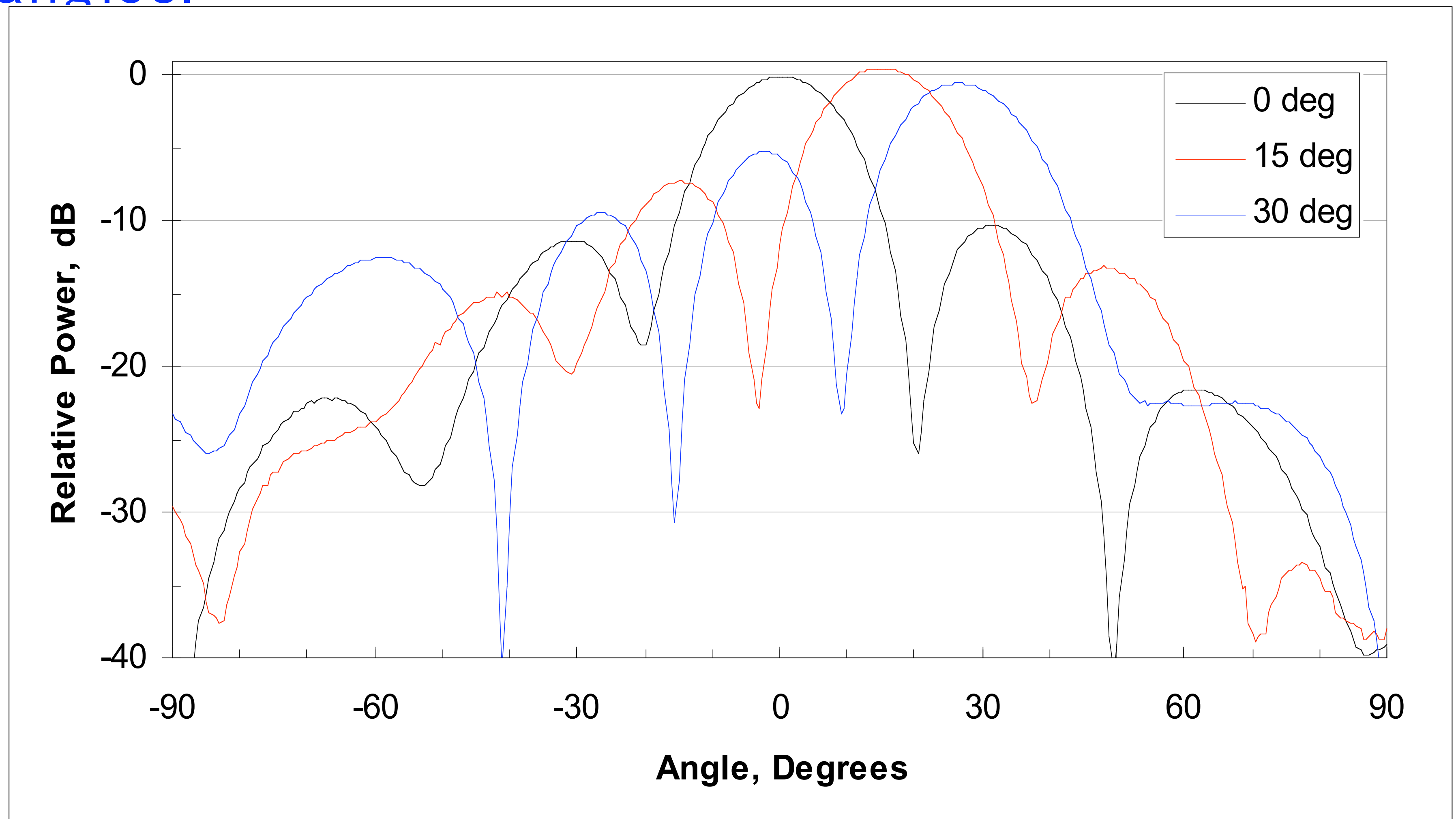




Close-up of the antenna

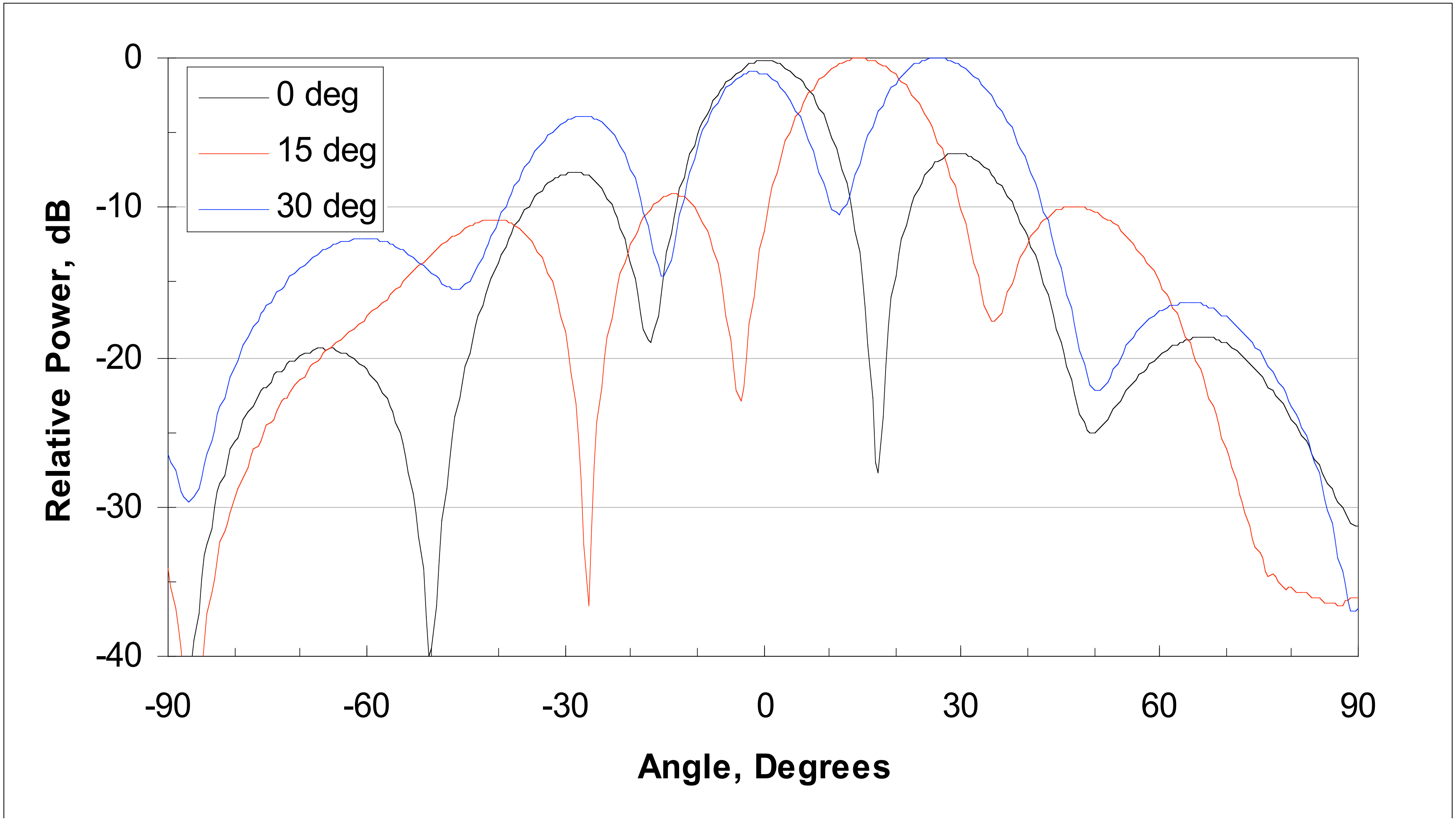
Measured Antenna Patterns

Antenna pattern in receive for 0°, 15°, 30° scan angles.



Measured Antenna Patterns

Antenna pattern in transmit for 0°, 15°, 30° scan angles.



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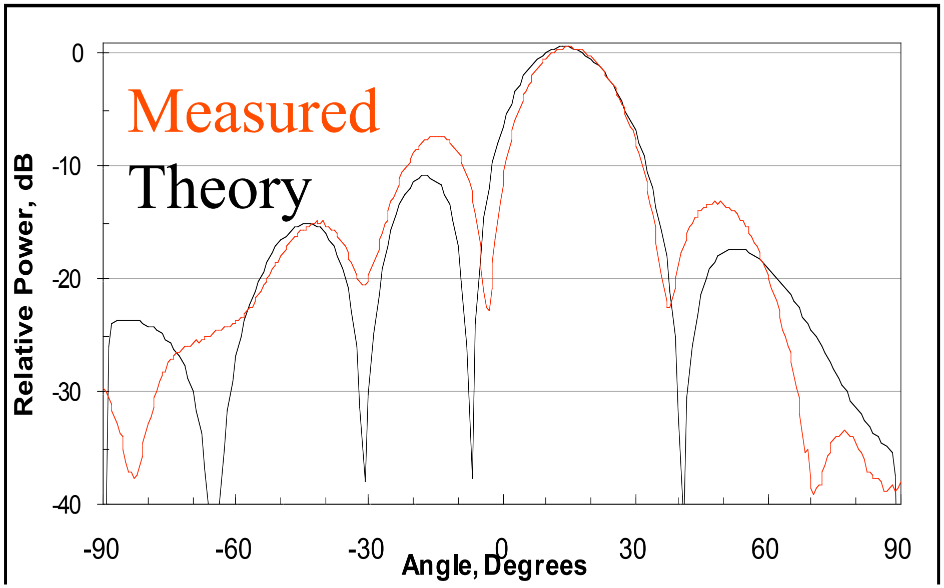
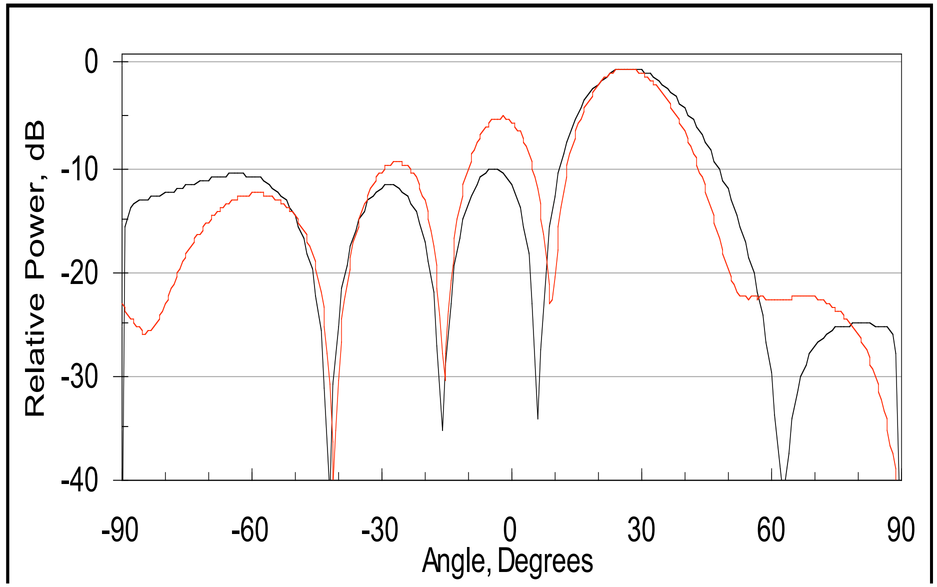
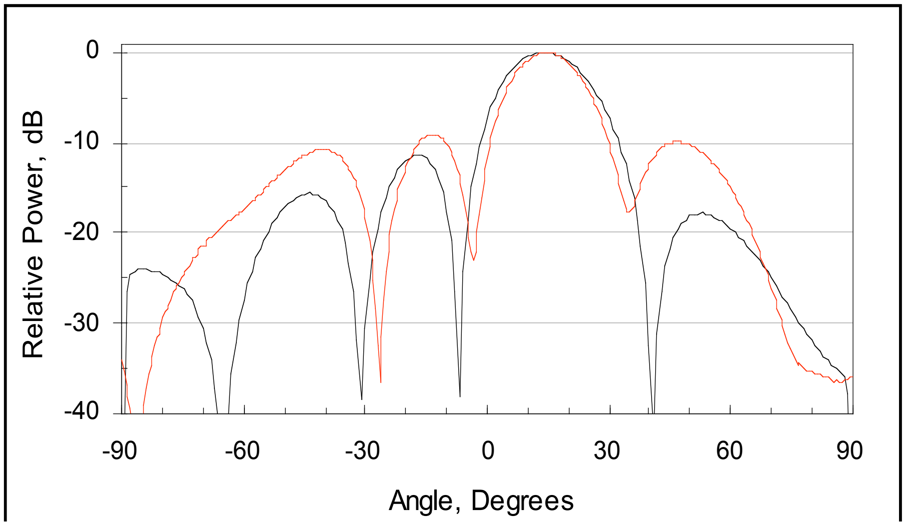
Theory vs. Measurement



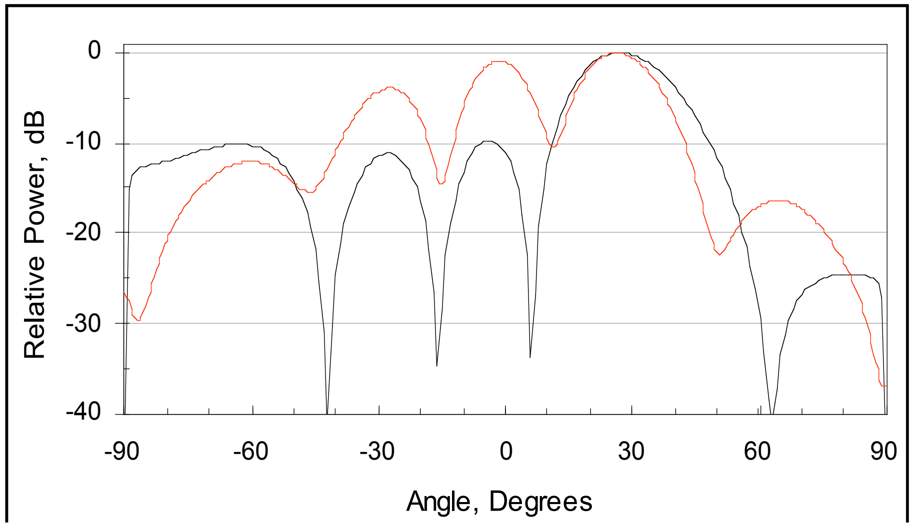
15° Angle in Receive



30° Angle in Receive



15° Angle in Transmit



30° Angle in Transmit

Future Work: T/R Module Control

Design Requirements and Constraints

- Each T/R module has 6-phase bits that must be independently controllable
- Future configurations will include a programmable attenuator, adding even more control bits
- Wiring must be minimized in order to reduce parasitic coupling to antennas and T/R modules
- Approach must be scalable to large arrays

T/R Module Control

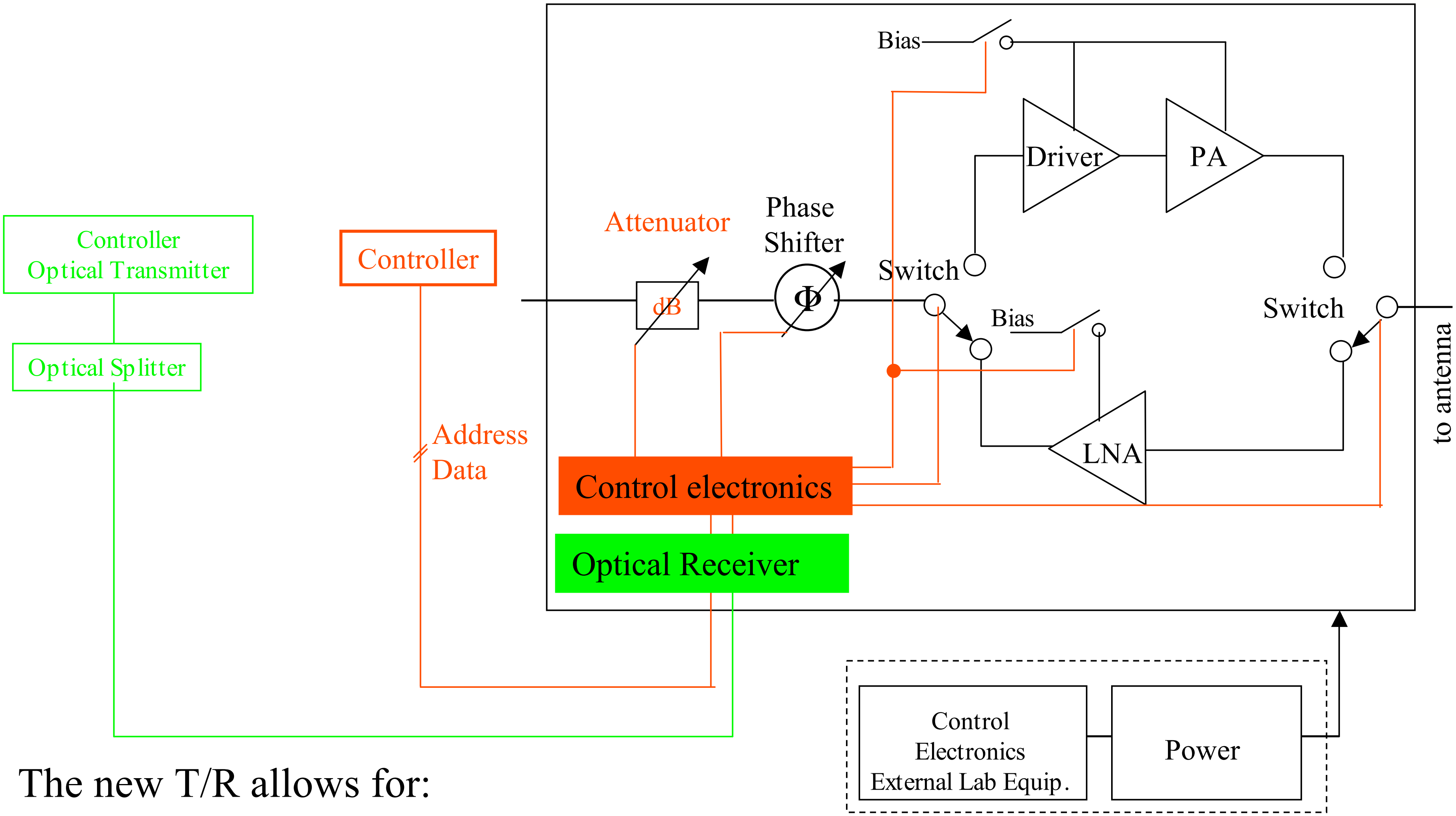
Types of control methodologies:

- Parallel
- Serial

- **Wired:**
  - Copper wire connections (lines etched in membrane)
  - Optical Fiber
  - RF/Digital Multiplexed

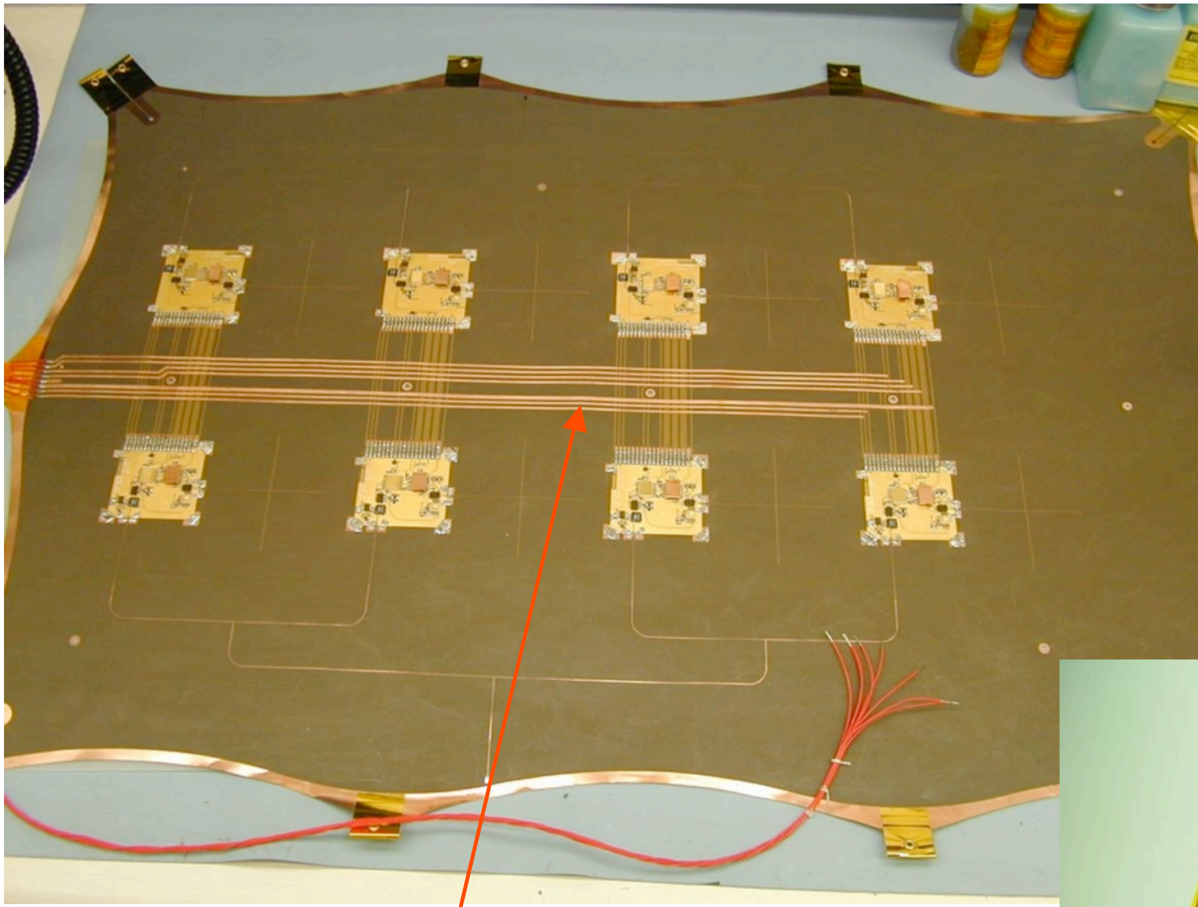
- **Free Space**
  - Free Space Optical
  - Free Space IR

New T/R Design (Electrical & Optical Control)

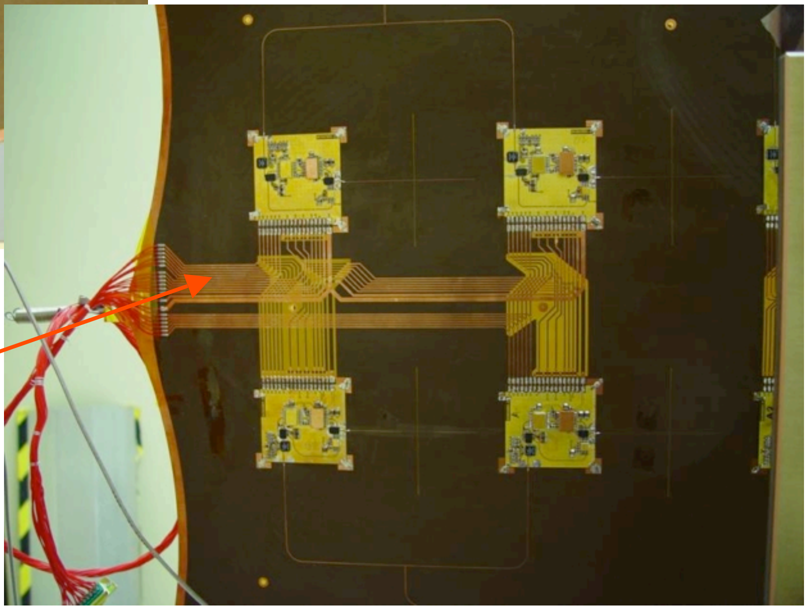


The new T/R allows for:
- Integrated control (reduces control lines on the array)
- Addition of programmable attenuator for gain control (improved pattern/sidelobes)
- On/Off T/R switch for individual T/R control

New Active Array (Electrical Control)



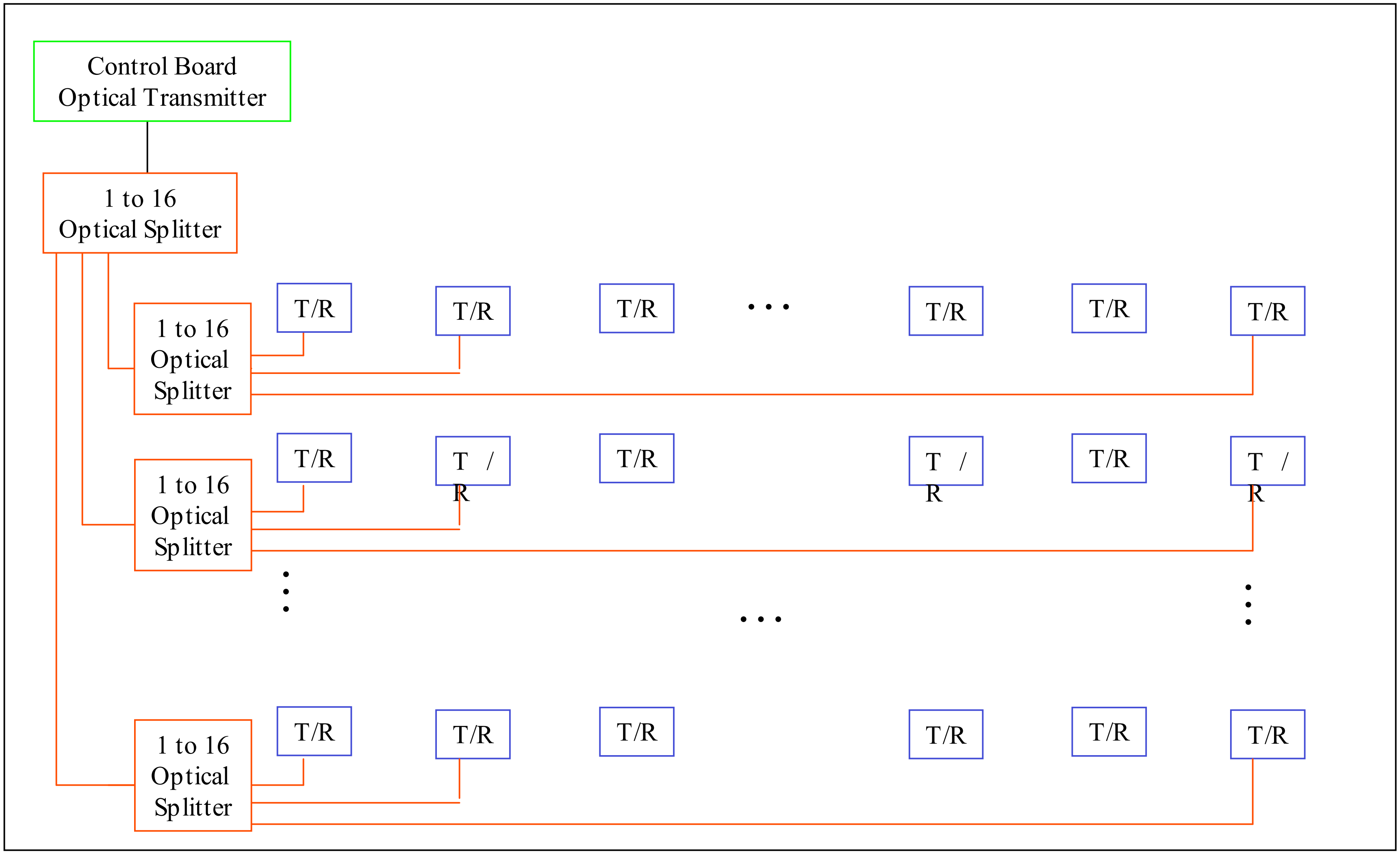
Old Active Array
no controls



New Active Array with Electrical Control

Reduced number of control lines compared to the previous Array

Active Array (Optical Control)



Summary and Future Work

Past Accomplishments:

- We have developed a flex-compatible T/R module
- Using this T/R Module we have demonstrated an active membrane phase array (0.6x0.3m)

Future Work:

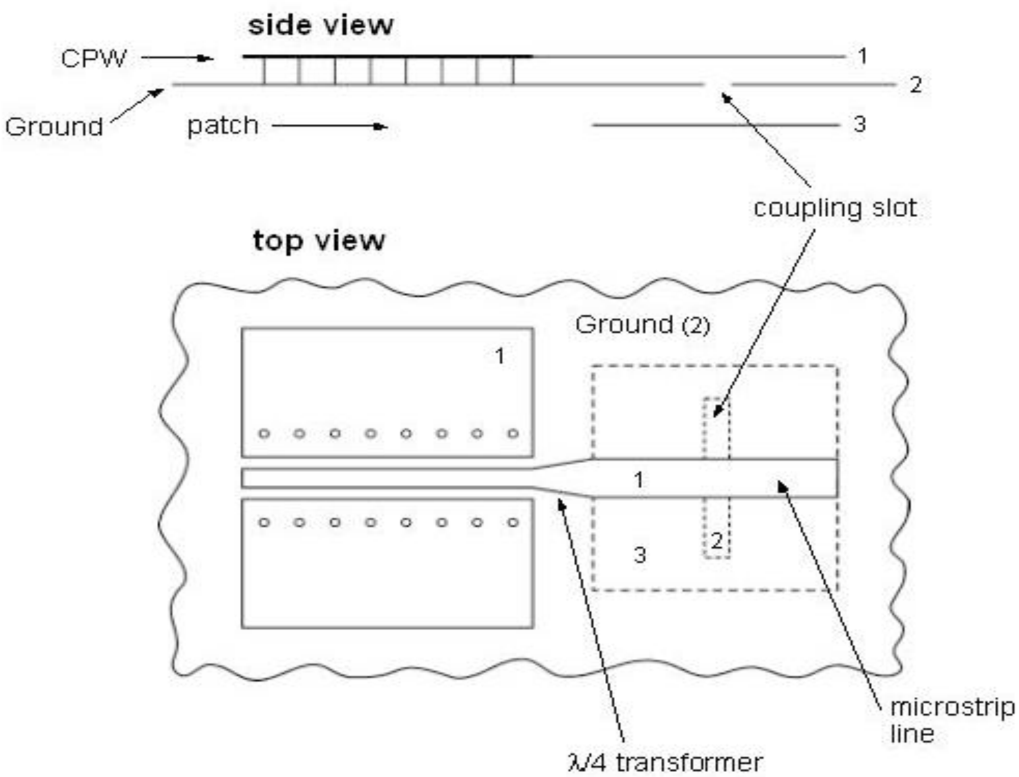
- Integrate T/R module controls with the T/R and demonstrate a 2x4 array (current ACT)
    - electrical control
    - optical control

- Develop a 2x3m membrane antenna (IIP)

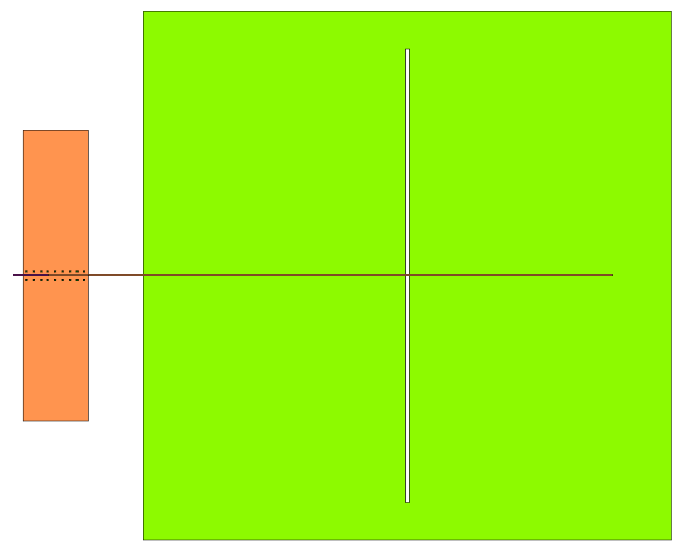
Backup Slides

Antenna Feed

Antenna description



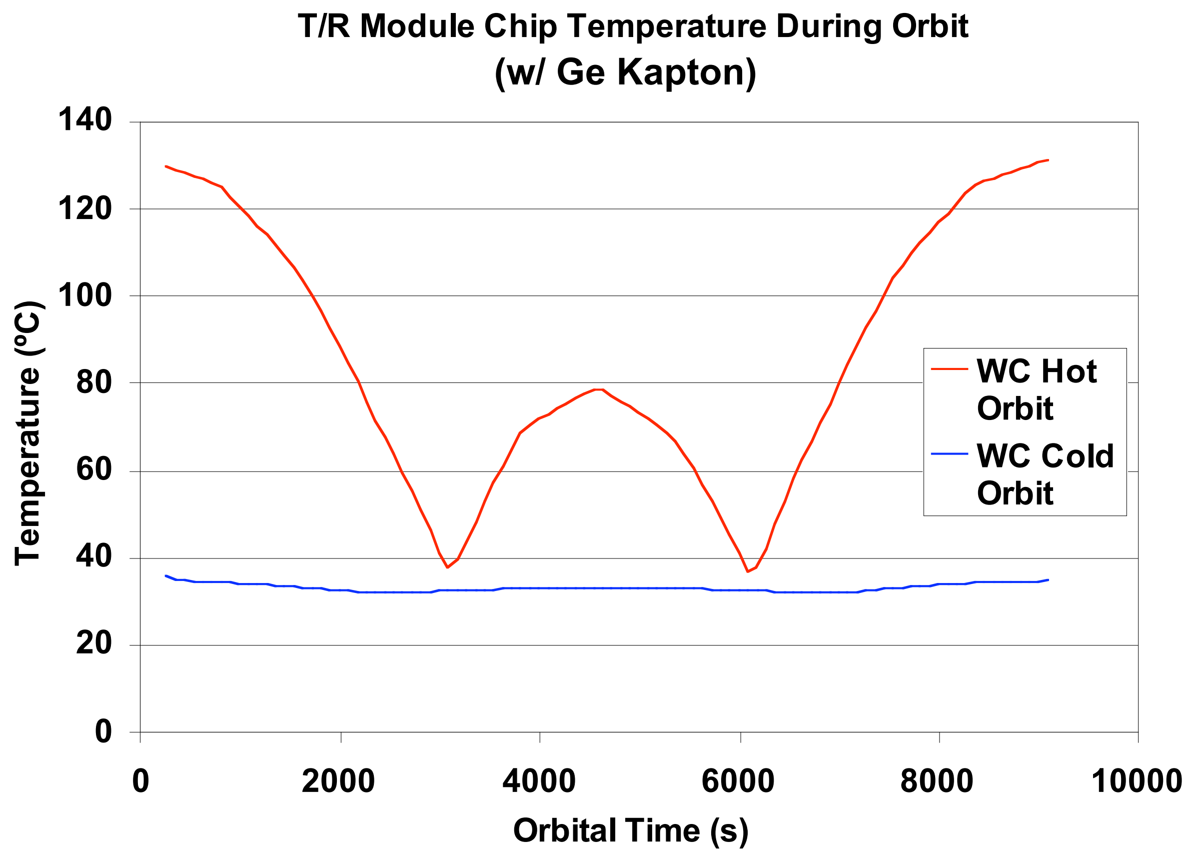
Simulation configuration



9.27 cm square

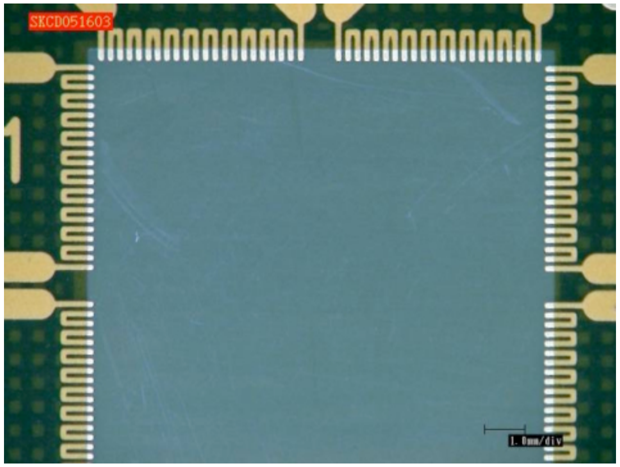
T/R Module Unit Cell Thermal Model Results

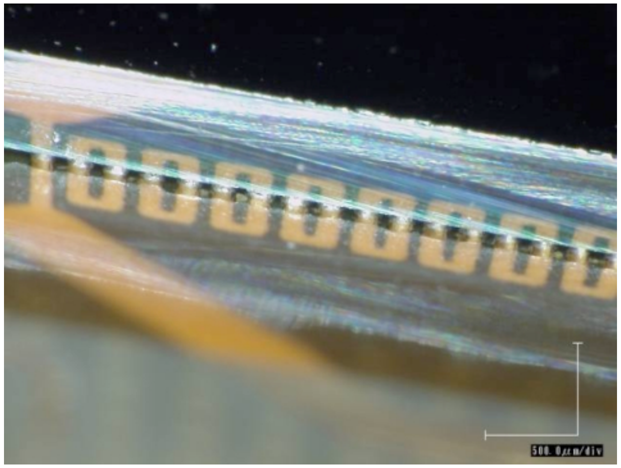
- Bare Kapton is semi-transparent (40%) and allows direct solar heating of ground plane
- Painted Kapton produces better results (90 C max, 15 C min chip temp), but is unrealistic
- Germanium coated Kapton improves thermal performance and is RF transparent

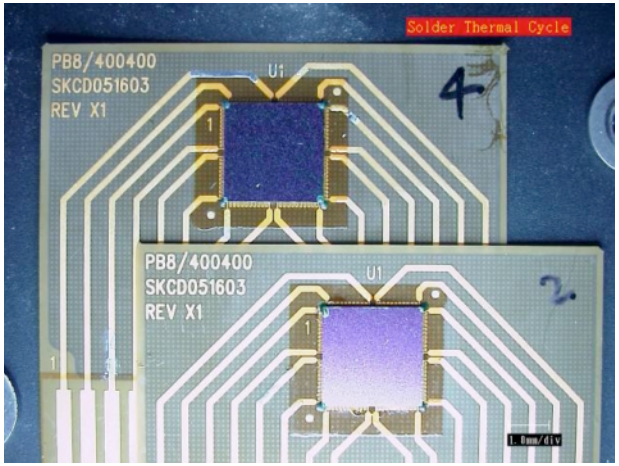


Flip Chip on Flex-Solder

- Fabrication of the daisy chain circuitry on the Cu-clad flex substrate resulted in smaller bondpads than designed and significant misalignment of the solder mask.
- Since the features required for flip chip processing are at the limit of the board level fabrication technology, design changes resulting from these limitations became necessary.
- Ultimately, solder daisy chain assemblies exhibiting 100% functionality were produced.
- Samples exposed to 10 thermal cycles (-55 to 125°C) survived successfully.

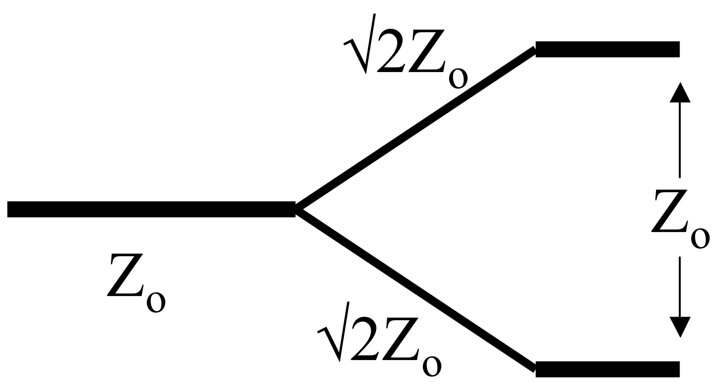


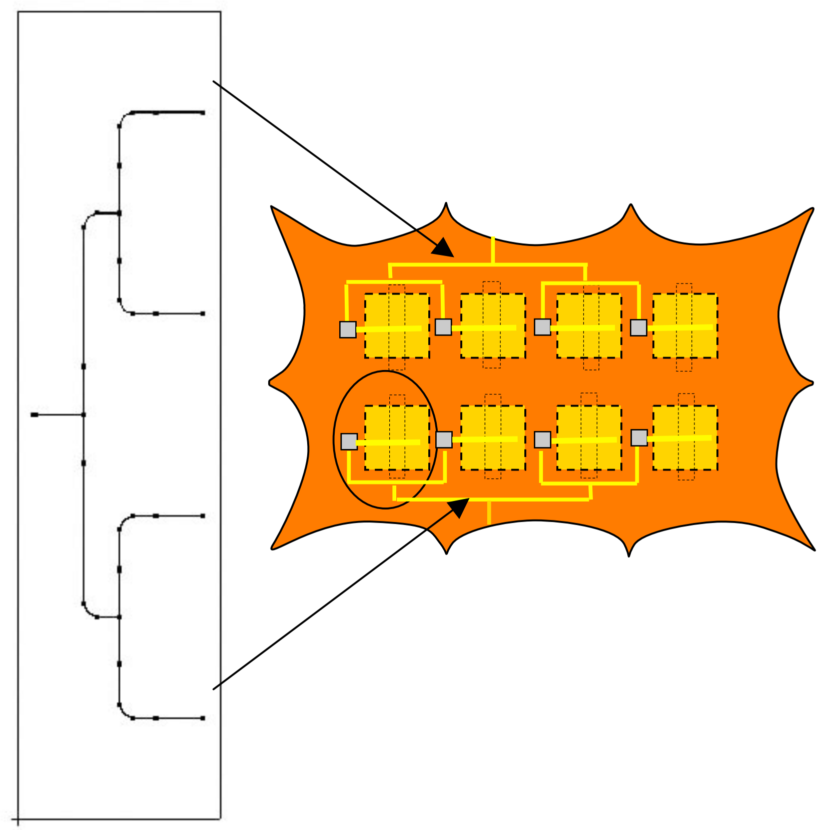




4-Way Divider on Flex

- 2-mil flex-substrate yields 50Ω at 4.3-mil line width
    - Etching tolerance = +/-10%, with minimum of +/- 0.3 mil
    - 50Ω Wilkinson requires at least 70Ω line (@2.2-mil



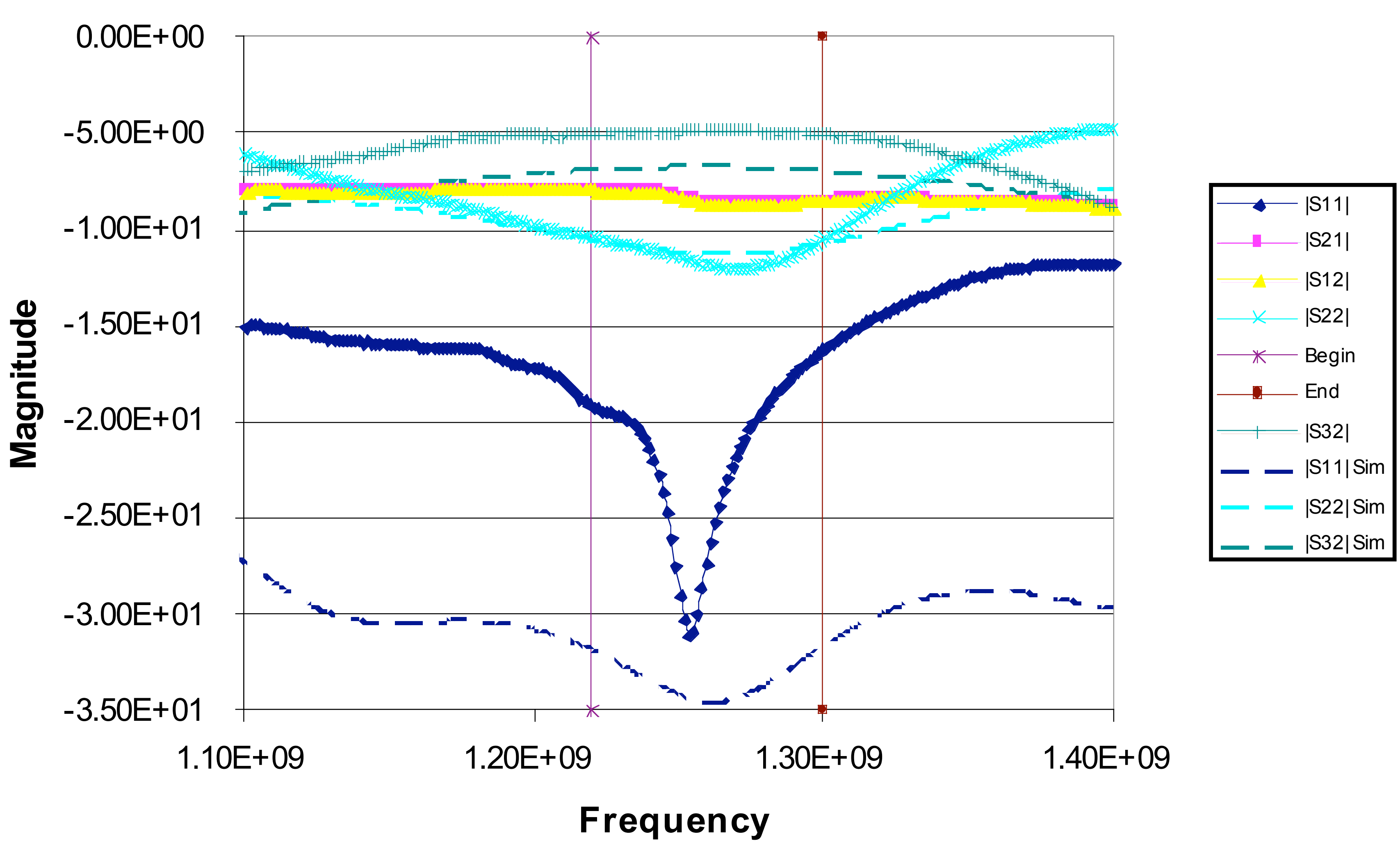


- Transform to 25Ω (12 mils)
- Divider @ 35Ω (7.5 mils)
- Transform back to 50 Ω
- Must meet 80MHz requirement

See Appendix A for measurement results

Divider Measurement Results

4-Way Pyralux AP 25/50-Ohm Divider



T/R Control Approaches

Parallel Control

- One wire per bit
- Pros:
  - Simple
  - Robust
  - Fast
- Cons:
  - Number of wires increases linearly with array size; impractical for all but the smallest arrays

Two-Wire Serial

- Two wires connect to all modules, data sent serially
  - Clock signal
  - Data signal
- Pros:
  - Only two wires for all modules
- Cons:
  - Slower
    - Each module must be addressed on at a time
    - Wiring layout may limit maximum speed
  - Requires interface chip in T/R module

Optical

- Data sent serially through optical fiber
- Pros:
  - No extra wires
  - Very high data rate
- Cons:
  - Requires optical receiver and digital interface at T/R module
  - Difficult to align and attach fibers

RF Multiplexed

- Data sent serially through RF signal path using a carrier outside the radar band
- Pros:
  - No extra wires!
- Cons:
  - Requires both a digital interface and demultiplexing circuitry at T/R module
  - Could interfere with radar receiver (more design and testing required)